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REMARKS

An Information Disclosure Statement was mailed November 28, 2001. Enclosed is a copy thereof and of the form 1449 which was enclosed therewith. Applicant has to date received no information that all of the references disclosed therein have been considered by the Examiner. As discussed in the previous Amendment, it is respectfully requested that the Examiner consider the additional references disclosed therein.

Independent claims 1 and 15 have been rejected under 35 USC 102(b) as being anticipated by U.S. patent 4,763,032 to Bramm et al, and independent method claim 20 has been rejected as not being unobvious in view of the structure in Bramm et al.

The claims have been amended to more clearly recite what Applicant regards as the invention. As amended, claim 1 recites that the coil is wound as a toroid over said respective at least one stator magnet and with said respective at least one rotor magnet disposed substantially within the toroid. Support therefor is found at page 6, lines 21 to 26, of the specification and in FIGS. 1 and 3 of the drawings.

Claim 15 has been canceled, and claim 17 rewritten in independent form and amended to recite that the reference electrical energy is about zero. Support for this recitation is found in claim 18, as originally filed. Also see the first full paragraph on page 12 of the specification. Claim 18 has been accordingly canceled, and the dependency of the claims dependent on now-canceled claim 15 have been accordingly changed to be dependent on claim 17, as amended. Method claim 20 has been canceled, and claim 21 rewritten in independent form and amended to recite that the reference electrical energy is selected to be about zero. Support for this recitation is discussed above. Claim 18 has been accordingly canceled. Claims 17 and 18 have been rejected under 35 USC 103(a) as not being patentable over

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Bramm et al in view of U.S. patent 5,928,131 to Prem, the Examiner stating that it would not have been unobvious to modify the circuit in Bramm's apparatus having the comparator as taught by Prem and that Bramm et al discloses a reference electrical energy of about zero volts (0.1 W). Claims 21 and 22 have been rejected has not being unobvious in view of the structure in Bramm et al and Prem. The remaining claims have been rejected over Bramm et al by itself or in combination with Prem. For the reasons provided hereinafter, it is respectively submitted that each of the claims, as amended, is not anticipated by and is unobvious over the references of record.

The present invention is directed to a magnet assembly for bearing a rotor both radially and axially, i.e., to act as both radial and thrust bearings, and, in accordance with an object of the present invention, to provide such an assembly which is simplified, compact, and reliable. The rotor loads (both radial and thrust) are borne by a pair of axially spaced combinations, each combination including at least one permanent magnet on each of the stator and the rotor on opposite sides of a respective axially extending gap portion and polarized to levitate the rotor.

In order to achieve acceptable angular and axial stability, in accordance with a feature of the present invention, the rotor magnets are offset axially from the stator magnets such that the rotor magnets are each offset axially inwardly from the corresponding stator magnet or such that the rotor magnets are each offset axially outwardly from the corresponding stator magnet. The resulting opposition in axial forces allows a zero force balance to be attainable.

Magnet flux between the respective stator and rotor magnets is modulated by an electrically energizable coil, i.e., the coil flux interacts with both the stator and rotor flux to both

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influence the radial stiffness and provide axial control. The current direction and magnitude in the coils will vary their magnetic flux which in turn, due to interaction of the coil magnetic flux with the magnetic flux between the stator and rotor magnets, will vary the axial forces to achieve stability of the zero force balance position of the rotor. See the second full paragraph on page 7 of the specification. This is in addition to regulating radial as well as axial stiffness (damping).

In order to couple the coil flux with the flux of both the stator and rotor magnets to achieve the above objectives, in accordance with the present invention, the coil is wound as a toroid over the respective stator magnet or magnets and with the respective rotor magnet or magnets disposed substantially within the toroid, as illustrated in FIGS. 1 and 3.

As discussed above, the electrically energized coil or toroid, which is composed of electrically conductive wire (such as copper), modulates the magnetic flux between the rotor and stator via control circuitry that regulates the energy to the coil to stabilize and control position of the rotor in the axial plane. The coil and control circuitry may also be used to independently modulate the magnetic flux between the rotor and stator so as to affect vibration oscillations and magnetic stiffness in the radial plane.

For axial control, the modulation of the electrical current in the coil can be used to alter the rotor axial position through minimizing the net axial force and hence minimizing the electrical current in the coil ideally to zero. To damp out the axial vibrations in a timely fashion and in response to external pulsation sources such as would be present in the native heart, another portion of the electrical circuitry can be used to modulate the energy to the electrical coil or toroid by periodically varying the coil current in synchronization with the

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imposed vibrations to introduce a component of electrical energy to the coil that is opposite in phase to the velocity component of the rotor axial motion thereby producing a damping force opposing the experienced axial oscillations. The damping force introduced through the electric control circuitry minimizes the magnitude of axial oscillations due to the inherent axial instability of the permanent magnet levitation magnets as identified by Earnshaw's Theorem. The net effect, when combined with the control circuit logic that reduces the net axial force acting on the rotor to near zero, is to more quickly reduce axial oscillations even in the presence of imposed axial fluid pulsations or pulsations due to imperfections in impeller/volute manufacturing.

The magnetic flux modulation of the present invention may also be used to produce pulsatility in the LVAD (left ventricular assist device or pump) fluid output by causing the rotor to undergo axial oscillations in synchronization with the fluid pulsatility inherent in a pumping heart.

Due to the construction of the permanent magnets and the electrical coil, which surrounds both the stator and rotor magnets, the electronic control circuitry can be used to modulate the electrical current in the toroidally shaped coil to alter the stiffness and introduce damping to affect and minimize rotor radial motion. The introduction of radial damping will help to reduce the magnitude of radial vibrations caused by both fluid and rotor unbalance forces. The electrical circuitry that is used to modulate the energy to the electrical coil or toroid is to be used to introduce a component of electrical energy to the coil that is opposite in phase to the velocity component of the rotor radial motion to produce a damping force opposing the rotor radial oscillations. The electric circuitry may also be used, either alone or in conjunction with the radial damping to

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increase or decrease the radial magnetic stiffness. Such variation in radial stiffness will alter the rotor dynamic response so as to minimize the rotor motion under the influence of rotor or fluid unbalance forces or other external forces such as shock or impact forces.

In order to attain a zero force balance position of the rotor wherein the current to the coils may be reduced to near zero so as to achieve low power consumption for such a magnet assembly, a first electrical circuit is provided for regulating electrical energy to the coils for maintaining a reference position of the rotor, and a second electrical circuit is responsive to feed-back of electrical energy to at least one of the coils for modifying the reference position. See the specification from page 9, fifth line from bottom, to page 12, line 5.

In order to be able to distinguish between an outside axial force or just instability causing a change in impeller position and thus reliably (not prone to instability error) provide low power consumption for such a system, the second circuit includes a comparator for comparing electrical energy to the coil with a reference electrical energy of about zero and an integrator of the differences therebetween. Thus, as illustrated in FIG. 4, a current transducer 104 outputs a voltage to line 102 which is representative of the current flowing in the coils 54a and 54b. A force reference signal 100 of near zero volts is combined in comparator 103 with voltage in line 102 from current transducer 104. The resulting difference voltage is outputted onto line 106 to integrator 76 where it is integrated and compared in comparator 75 with the position reference voltage 72 to provide a modified position reference voltage or signal 78. This integration continues until the voltage in line 106 goes to (or near) zero, which means that a new force balance position is

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attained wherein the current supplied to coils 54 by PID controller 90 is essentially zero at this new zero force balance position. It is this modified position reference signal that is compared with the rotor position signal 86 in comparator 87 and the difference supplied as signal 88 to PID controller 90. As a result, mere instabilities in the system (which do not amount to changes in position caused by outside forces) desirably do not result in a new force balance position.

The use of the same magnets for bearing both axial and radial loads in accordance with the present invention advantageously allows greater compactness of the pump to be achieved, and the magnetic flux between the rotor and stator magnets may be modulated by use of the coil to achieve good radial and angular stiffness to support the rotor while maintaining axial stability. While blood flowing through the gap between the rotor and stator does provide some radial stiffness, it is more important to achieve desired radial stiffness when the rotor/stator gap contains air. Moreover, the axial position reference is continuously re-set based on electrical energy feedback to reliably achieve zero force balance, whereby a minimum of current (energy) may be used to stabilize the bearing thereby to prevent blood damage due to heat (when the apparatus is used as a blood pump) as well as to provide more economical operation. In addition, the combined axial and radial bearings of the present invention allows a streamlined flow path through the apparatus, when used as a blood pump, which is desirable for preventing blood damage.

Bramm et al ('032) discloses a magnetically suspended and rotated rotor having an axially polarized cylindrical or bar permanent magnet at each end of the rotor. An axially polarized permanent magnet ring is provided at each end of the stator to magnetically interact therewith respectively to levitate the

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rotor. The stator magnet rings are offset axially outwardly of the rotor magnets respectively. An electromagnet on the stator exerts a control force on the rotor magnet to keep the impeller at a position "in which the absolute energy requirement of the electromagnetic arrangement is minimized without external forces" (col. 3, lines 55 to 58). For axial position control, a control circuit (7 in FIG. 1 thereof) having amplifier devices (30, 31, and 32 in FIG. 1 thereof) is connected to the output of a position sensor operating circuit (9 in FIG. 1 thereof) at which a signal is received which represents the actual position of the rotor and controls the electric current intensity of the electromagnets so that the actual value of rotor position conforms with a predetermined desired position thereof. This control circuit also has a superimposed regulator (33 in FIG. 1 thereof) which comprises a detection device (44 in FIG. 1 thereof) which may be a current meter which measures current flowing through the electromagnets or through the control loop. The detection device delivers to a comparison device (46 in FIG. 1 thereof) the energy requirement values of the rotor bearing to be compared. The comparison device outputs to an adjusting device (45 in FIG. 1 thereof) which is a control device which responds to the output signal of the detection device and to the output signal of the comparison device and which releases a signal by which the desired value of the axial position of the rotor is modified via a line (48 in FIG. 1 thereof) which leads to the pre-amplifier 30 or servo-amplifier 31. The comparison device compares the energy requirements of the electromagnets and of the entire control loop in different axial positions of the rotor and, based on this comparison, releases an output signal to the adjusting device which causes it to shift the axial position of the rotor. The comparison device compares a previous energy requirement with the new energy requirement and adjusts the rotor

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position gradually by successive energy requirement comparisons and by successive modifications of the desired value for the axial rotor position by, in each case, small amounts until the energy requirement (stated, at col. 5, line 66, to be, for example, 0.1 watt) has reached its minimum (see col. 17, line 25, to col. 19, line 29, thereof).

It should first be noted that, at col. 11, line 23, of Bramm et al, "stator 5" should be "rotor 1" since the magnet 18c or 18d is located on the rotor in FIG. 6 thereof. As stated in that paragraph, when so corrected, the electromagnets of Bramm et al interact magnetically with the rotor permanent magnets, and the rotor permanent magnets interact magnetically with the stator permanent magnets. It is further stated that the axial position of the rotor is centered and stabilized by the electromagnets interacting with the rotor permanent magnets. Moreover, at col. 5, lines 12 and 13, of Bramm et al, the electromagnetic arrangement is characterized as "an axial electromagnet." Thus, unlike the present invention, Bramm et al does not teach or suggest that its electromagnetic coils influence its stator permanent magnets with the result that, unlike the present invention, the Bramm et al apparatus may be said to have a radial bearing which is magnetically separate from its axial bearing. As a result, the Bramm et al electromagnets and magnets would not be able to control radial stiffness, as provided by the present invention. Moreover, Bramm et al does not teach or suggest the coil being wound as a toroid over said respective at least one stator magnet and with said respective at least one rotor magnet disposed substantially within the toroid for modulating magnetic flux between said respective stator and rotor magnets, as provided by the present invention, for achieving the influencing of the magnetic fields of both the rotor and stator magnets in order to control radial stiffness as well as to maintain

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stability axially.

Furthermore, Bramm et al does not teach or suggest a comparator which compares electrical energy to at least one of the coils (which interacts magnetically with a permanent magnet on a rotor for controlling axial position thereof) with a reference electrical energy of about zero and an integrator of the differences therebetween, as provided by the present invention, in order to more reliably achieve a zero force balance position when the rotor is acted upon axially by outside forces.

Prem discloses a fluid pump magnetically suspended by permanent stator and rotor magnets and a Lorentz-force actuator formed by an assembly of permanent magnets, coils, and back irons and employed as an axial bearing for the pump. A circuit is provided for sensing the axial position of the rotor by utilizing the ratio of the inductances of coils of an axial position sensor, the circuit including as a component a comparator for detecting and controlling the sign of a sine wave.

Since the comparator of Prem is merely a component in a circuit for sensing axial position of a rotor, it does not provide any contribution to the problem associated with making Bramm et al's axial positioning more reliable. It is respectfully submitted that there is no impetus or motivation for combining Prem with Bramm et al. Moreover, even if the references were properly combinable, the combination still would not result in the present invention. Thus, the combination of Prem and Bramm et al still does not teach or suggest a comparator which compares electrical energy to at least one of the coils (which interacts magnetically with a permanent magnet on a rotor for controlling axial position thereof) with a reference electrical energy of about zero and an integrator of the differences therebetween, as provided by the present invention, in order to more reliably achieve a zero force balance position

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when the rotor is acted upon axially by outside forces.

Neither Bramm et al or any other of the art of record, whether taken together or individually, discloses, teaches, or suggests apparatus wherein first and second axially spaced combinations each includes at least one permanent magnet disposed on each of a rotor and a stator on opposite sides of a respective axially extending gap portion and polarized to levitate the rotor and an electrically energizable coil wound as a toroid over the respective at least one stator magnet and with the respective at least one rotor magnet disposed substantially within the toroid for modulating magnetic flux between the respective stator and rotor magnets, electrical circuitry for regulating electrical energy to the coils for stabilizing said rotor axially, and wherein the rotor magnets are offset axially of the stator magnets respectively such that the rotor magnets are offset axially inwardly of the corresponding stator magnets or such that the rotor magnets are offset axially outwardly of the corresponding stator magnets, as claimed in claim 1, as amended, so as to allow a zero force balance to be attainable as well as to allow the regulation of radial stiffness (damping) in order to provide a simplified, compact, and reliable magnet assembly which allows a streamlined pump flow path to be achieved and which bears a rotor both radially and axially, i.e., to act as both radial and thrust bearings. Therefore, it is respectfully submitted that claim 1, as amended, is novel and unobvious over the prior art and is therefore patentable.

Neither Bramm et al, Prem, or any other of the art of record, whether taken together or individually, discloses, teaches, or suggests apparatus wherein first and second axially spaced combinations each includes at least one permanent magnet disposed on each of a rotor and a stator on opposite sides of a respective axially extending gap portion and polarized to

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levitate the rotor and an electrically energizable coil for modulating magnetic flux between the respective stator and rotor magnets, a first electrical circuit for regulating electrical energy to the coils for maintaining a reference position of the rotor, and a second electrical circuit responsive to feed-back of electrical energy to at least one of the coils for modifying the reference position, wherein the second circuit includes a comparator for comparing electrical energy to at least one of the coils with a reference electrical energy of about zero and an integrator of the differences therebetween, as claimed in claim 17, as amended, in order to provide a simplified, compact, and reliable magnet assembly which allows a streamlined pump flow path to be achieved and which bears a rotor both radially and axially, i.e., to act as both radial and thrust bearings, and to attain a zero force balance position of the rotor wherein the current to the coils may be reduced to near zero so as to achieve low power consumption for such a magnet assembly. Therefore, it is respectfully submitted that claim 17, as amended, is novel and unobvious over the prior art and is therefore patentable.

Neither Bramm et al, Prem, or any other of the art of record, whether taken together or individually, discloses, teaches, or suggests a method for bearing a rotor wherein first and second axially spaced combinations each including at least one permanent magnet disposed on each of the rotor and a stator are provided on opposite sides of a respective axially extending gap portion and polarized to levitate the rotor, an electrically energizable coil is provided for each of the combinations, electrical energy to the coils is regulated for maintaining a reference position of the rotor, and the reference position is modified in response to feed-back of electrical energy to at least one of the coils, wherein the step of modifying the reference position comprises comparing electrical energy to at

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least one of the coils with a reference electrical energy, integrating the differences therebetween until a difference of about zero is attained, and selecting the amount of reference electrical energy to be about zero, as claimed in claim 21, as amended, in order to bear a rotor both radially and axially with a simplified (which allows a streamlined flow path to be achieved), compact, and reliable magnet assembly, i.e., wherein the same magnet assembly acts as both radial and thrust bearings, and to attain a zero force balance position of the rotor wherein the current to the coils may be reduced to near zero so as to achieve low power consumption for such a magnet assembly. Therefore, it is respectfully submitted that claim 21, as amended, is novel and unobvious over the prior art and is therefore patentable.

Since the remaining claims, as amended, are dependent on one or the other of claims 1, 17, and 21, as amended, it is respectfully submitted that they are also patentable for at least the same reasons respectively.

Since each of the claims, as amended, has been shown to be patentable, it is respectfully submitted that this application is in condition for allowance, and such is respectfully requested. If it would aid in advancing this application to issue, the Examiner is respectfully urged to call the undersigned attorney for Applicant at the number below.

Respectfully submitted,



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Enclosures

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